PCB Congener Concentrations in Puget Sound Sediments

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[Editor's note: Tables and Figures for Dutch et al appear at the end of this paper.]

Abstract
Concentrations of 19 PCB congeners were determined in 300 sediment samples collected throughout Puget Sound during 1997-1999 as part of a joint monitoring project conducted by the Washington State Department of Ecology and the National Oceanic and Atmospheric Administration. The highest total PCB congener concentrations were measured in samples collected from the Whidbey Basin and Central Puget Sound regions, specifically, from the urban/industrialized embayments of Everett Harbor, Elliott Bay, Commencement Bay, and around Bainbridge Island, with concentrations diminishing from the head to the mouth of these embayments. National sediment guideline values for total PCB congener concentrations were exceeded at 14 of the 300 stations, again, in some of the most urban/industrialized embayments of Puget Sound (i.e., Port of Everett, Elliott Bay, lower Duwamish River, Thea Foss Waterway, Hylebos Waterway). Lowest PCB concentrations were recorded in samples from the Strait of Georgia, Admiralty Inlet, Hood Canal, and southern Puget Sound.

Introduction
The Washington State Department of Ecology (Ecology) and the National Oceanic and Atmospheric Administration (NOAA) conducted a joint monitoring program from 1997 through 1999 to quantify the magnitude and extent of toxicity, chemical contamination, and impacted benthos in the sediments of Puget Sound (Long et. al. 1999, 2000, 2002). This joint effort combined the Puget Sound Ambient Monitoring Program's (PSAMP) Sediment Component administered by Ecology and the National Status and Trends (NS&T) Program conducted by NOAA. Data from this survey were evaluated to identify geographic patterns in sediment quality, the spatial extent of degraded conditions, and the relationships among individual measures. Sediments from 300 stations, chosen with a random, stratified sampling design, were collected from Puget Sound basins and channels extending from the U.S./Canada border to the southern-most bays and inlets near Olympia and Shelton, including portions of Admiralty Inlet and Hood Canal. As part of this study, samples were analyzed to determine concentrations of polychlorinated biphenyls (PCBs), including 8 PCB Aroclors and 19 PCB congeners. Results of the PCB congener analyses are summarized in this paper to illustrate the levels and spatial patterns of PCB congener contamination throughout Puget Sound.

Methods
Sediment samples were collected from the research vessel *Kittiwake* with a double 0.1 m^2, stainless steel, vanVeen grab sampler. A composite sediment sample was collected from each station, consisting of a homogenate of the top 2-3 cm of sediment from 3 to 6 grab samples. Samples were sent to Ecology's Manchester Environmental Laboratory (MEL) for PCB analysis. Sample extraction and analytical methods followed the protocols used by both Ecology (PSEP 1997) and NOAA (Lauenstein and Cantillo 1993). Specifically, analyses of chlorinated pesticides and PCBs followed U.S. EPA Method 8081/8082, using gas chromatography (GC) methods with dual dissimilar column confirmation and electron capture detectors. Reporting limits for PCB congeners ranged from 1 to 5 ppb, dry wt. The congeners that were quantified included:

8	44	77	118	138	180	206
18	52	101	126	153	187	
28	66	105	128	170	195	

Among these compounds, congeners 77, 105, 118, and 126 have shown dioxin-like properties, inducing responses in HRGS assays (Koh et al. 2001).

For this paper PCB congener data generated for each of the 300 stations were summarized and compared among stations and regions in Puget Sound to look for general trends, spatial patterns and gradients. The concentrations of the 19 individual PCB congeners were also summed for each station sampled using a value of zero for undetected concentrations. Summed concentrations are then multiplied by a factor of 2 to represent "total PCB concentrations." The sums were compared among stations and regions to identify any spatial patterns or gradients in concentrations and

for comparisons with sediment quality guidelines (SQGs) developed by NOAA from estuarine sediment data collected nationwide (Long et al. 1995), including Effects Range Low (ERL) and Effects Range Median (ERM) values.

Results

Station and Regional Data Summaries

Summary statistics of the concentration of each of the congeners measured for all 300 stations are displayed in Table 1. All 19 congeners were present in detectable concentrations in at least one sample. Congener 153 occurred at detectable concentrations in the most samples (135) and had the widest range of concentrations (i.e., a difference of 370 ppb from lowest to highest). The 4 congeners most frequently detected included 101, 118, 138, and 153, measured in 107-135 of the 300 samples. Ten congeners (28, 44, 52, 66, 105, 128, 170, 180, 187, and 206) were detected in 61-90 of the 300 samples. Five other congeners (8, 18, 77, 126, 195) were detected least frequently; in 4-39 of the 300 samples. Mean and median concentrations of total congeners for all 300 samples (80 ppb and 30 ppb, respectively) exceeded the ERL value of 22.7 ppb, but were lower than the ERM value of 180 ppb. The maximum concentration of 4892 ppb exceeded the ERM value by a factor of 27-fold.

Summary statistics for the total PCB congener values (ppb, dry wt.) were generated for stations grouped into each of 6 sediment-monitoring regions and for the total study area (Table 2). Mean and maximum concentrations of total congeners were highest in the Whidbey Basin region, which included Everett Harbor, and in the central Puget Sound region, which included Elliott Bay, Commencement Bay, and Sinclair Inlet. Mean concentrations in both regions exceeded the ERL value and the maximum concentrations exceeded the ERM value. Throughout the total study area, there were 14 samples out of the 300 tested in which total PCB congener concentrations exceeded the ERM value. Lowest concentrations generally occurred in the Strait of Georgia, Admiralty Inlet, Hood Canal, and southern Puget Sound. All of the congeners were undetected in the majority of the samples from these four regions.

The results of the various chemical, toxicity, and benthic analyses for each of the samples were weighted to the sizes of the strata in which they were collected (Long et al. 1999, 2000, 2002). Therefore, the spatial area of results that exceeded numerical critical values could be summed and reported as the percentages of the study area. The 14 samples in which the ERM value was exceeded represented about 4.2 km^2 of the Puget Sound study area. The total study area was estimated to cover about 2363 km^2. Therefore, the 14 samples in which these relatively high PCB concentrations occurred constituted about 0.2% of the total study area. Thirteen of these 14 samples were collected in the central Puget Sound region and one was collected in Everett Harbor in the Whidbey Basin region.

Spatial Patterns and Gradients in PCB Congener Concentrations

The concentrations of total PCB congeners (ppb, dry weight) calculated for all 300 stations were grouped into four percentiles and mapped to identify spatial patterns and gradients in distribution throughout Puget Sound (Figures 1-5). The results of the percentile calculations indicated that 50% of the summed PCB congener concentrations were measured at or below practical quantitation limits set by laboratory instrumentation. Twenty-five percent of the concentrations ranged from 0.4-17.0 ppb, 19% ranged from 17.1-162.9 ppb, and 6% ranged from 179.5-4658.0 ppb. Highest concentrations occurred in the Whidbey Basin and Central Puget Sound regions, especially in the urban/industrialized embayments of Everett Harbor, Elliott Bay, Commencement Bay, and around Bainbridge Island. High concentrations tended to diminish from the heads of the harbors to the mouths of the embayments.

Comparison of Total PCB Congener Concentrations with Sediment Guidelines

Concentrations of total PCB congeners for each station were compared with sediment guidelines derived with matching sediment chemical and biological effects data (Long et al. 1995) (Figures 6-9). Most samples from the central basin of Puget Sound, the basins and bays near Bainbridge Island, and Rich Passage had relatively low PCB concentrations, often less than the ERL value (Figure 6). Six samples from Sinclair Inlet and two from Dyes Inlet had concentrations that exceeded the ERL value, but not the ERM. PCB concentrations in most samples from Commencement Bay were less than the ERL, but the concentrations in 8 samples from several of the industrial waterways were much higher, exceeding the ERL and/or ERM values (Figure 7). Most of the samples from inner Everett Harbor had high PCB concentrations; whereas those from adjoining Port Gardner and Possession Sound were considerably lower (Figure 8). The highest concentration (4658 ppb) recorded in the survey was observed in one of the inner Everett Harbor samples. The majority (11) of the 14 samples in which total concentrations of PCBs exceeded the ERM came from Elliott Bay and the lower Duwamish River (Figure 9). Concentrations exceeded the ERL in nearly all of the Elliott Bay samples and exceeded the ERM in eleven samples. The East Duwamish River waterway sediments had particularly high concentrations.

Summary

Concentrations of 19 PCB congeners were determined in 300 sediment samples collected throughout Puget Sound during 1997-1999 as part of a joint monitoring project conducted by the Washington State Department of Ecology and the National Oceanic and Atmospheric Administration. The four congeners most frequently detected included 101, 118, 138, and 153, while five other congeners (8, 18, 77, 126, 195) were detected least frequently. The highest total PCB concentrations were measured in samples collected from the Whidbey Basin and Central Puget Sound regions, especially those from the urban/industrialized embayments of Everett Harbor, Elliott Bay, Commencement Bay, and around Bainbridge Island. These high concentrations tended to diminish from the head to the mouth of these embayments. Concentrations of total PCB congeners at 14 of the 300 stations (Port of Everett, Elliott Bay, lower Duwamish River, Thea Foss Waterway, Hylebos Waterway) equaled or exceeded the Effects Range Median (ERM) sediment guideline value of 180 ppb, a concentration previously associated with an elevated probability of adverse effects. Concentrations in 48 samples were equal to or greater than the Effects Range Low (ERL) guideline value of 22.7 ppb, but below the ERM, a concentration range within which adverse effects occasionally occur.

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Tables and Figures

Table 1. PCB congener summary (pbb, dry wt.) for the 1997-1999 PSAMP/NOAA Sediment Monitoring Survey (undetected concentrations included).

Chemical	Mean (ppb)	Median (ppb)	Minimum (ppb)	Maximum (ppb)	Range (ppb)	N	No. of Undetected Values	No. of Detected Values	% Undetected
PCB Congener 8	0.95	0.68	0.21	17.00	16.79	300	292	8	97.33
PCB Congener 18	0.98	0.66	0.19	15.00	14.81	300	265	35	88.33
PCB Congener 28	1.35	0.68	0.09	59.00	58.91	300	236	64	78.67
PCB Congener 44	1.23	0.68	0.21	34.00	33.79	300	236	64	78.67
PCB Congener 52	1.73	0.71	0.12	120.00	119.88	300	214	86	71.33
PCB Congener 66	1.33	0.66	0.10	62.00	61.90	300	215	85	71.67
PCB Congener 77	1.81	0.83	0.21	63.00	62.79	300	288	12	96.00
PCB Congener 101	2.75	0.73	0.07	120.00	119.93	300	183	117	61.00
PCB Congener 105	1.51	0.73	0.13	35.00	34.87	300	229	71	76.33
PCB Congener 118	2.83	0.74	0.10	240.00	239.90	300	193	107	64.33
PCB Congener 126	1.76	0.87	0.28	63.00	62.72	300	296	4	98.67
PCB Congener 128	1.19	0.70	0.07	20.00	19.93	300	226	74	75.33
PCB Congener 138	4.14	0.79	0.13	320.00	319.87	300	183	117	61.00
PCB Congener 153	4.50	0.78	0.06	370.00	369.94	300	165	135	55.00
PCB Congener 170	2.50	0.70	0.07	190.00	189.93	300	222	78	74.00
PCB Congener 180	3.85	0.74	0.11	350.00	349.89	300	210	90	70.00
PCB Congener 187	2.49	0.75	0.18	170.00	169.82	300	227	73	75.67
PCB Congener 195	1.80	0.64	0.12	260.00	259.88	300	261	39	87.00
PCB Congener 206	1.41	0.66	0.08	94.00	93.92	300	233	67	77.67
Total Congeners (x2)	80.23	29.63	8.37	4892.20	4883.83	300	NA	NA	NA

Table 2. Regional summary of total detected PCB congeners (ppb, dry wt.) in Puget Sound sediments from the 1997-99 PSAMP/NOAA Sediment Monitoring Survey.

Region	Mean (ppb)	Median (ppb)	Minimum (ppb)	Maximum (ppb)	Range (ppb)	N	No. of samples/region with all individual congeners undetected	No. of regional samples exceeding ERM (180 ppb) value and regional spatial extent (km2) of PCB congener contamination
Strait of Georgia	0.10	0.00	0.00	4.90	4.90	61	59	0 (0.0)
Whidbey Basin	131.16	0.00	0.00	4658.00	4658.00	39	20	1 (0.1)
Admiralty Inlet	2.42	0.00	0.00	21.78	21.78	9	8	0 (0.0)
Central Puget Sound	76.06	12.82	0.00	1756.60	1756.60	128	30	13 (4.1)
Hood Canal	0.59	0.00	0.00	5.42	5.42	21	18	0 (0.0)
South Puget Sound	3.34	0.00	0.00	63.98	63.98	42	27	0 (0.0)
Total Study Area	**50.11**	**0.00**	**0.00**	**4658.00**	**4658.00**	**300**	**162**	**14 (4.2)**

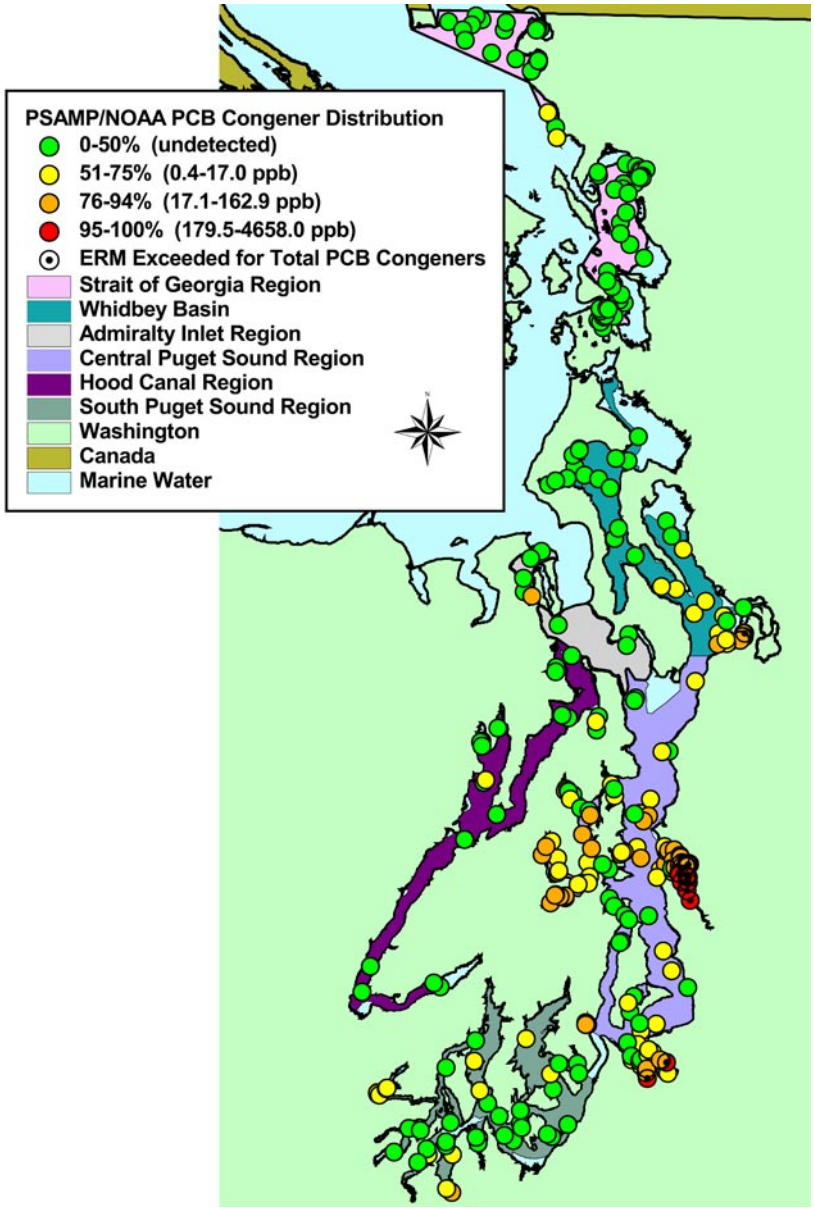

Figure 1. Distribution of total PCB congener concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey, and comparison with nationally derived sediment quality guidelines (ERL and ERM, Long et al. 1995).

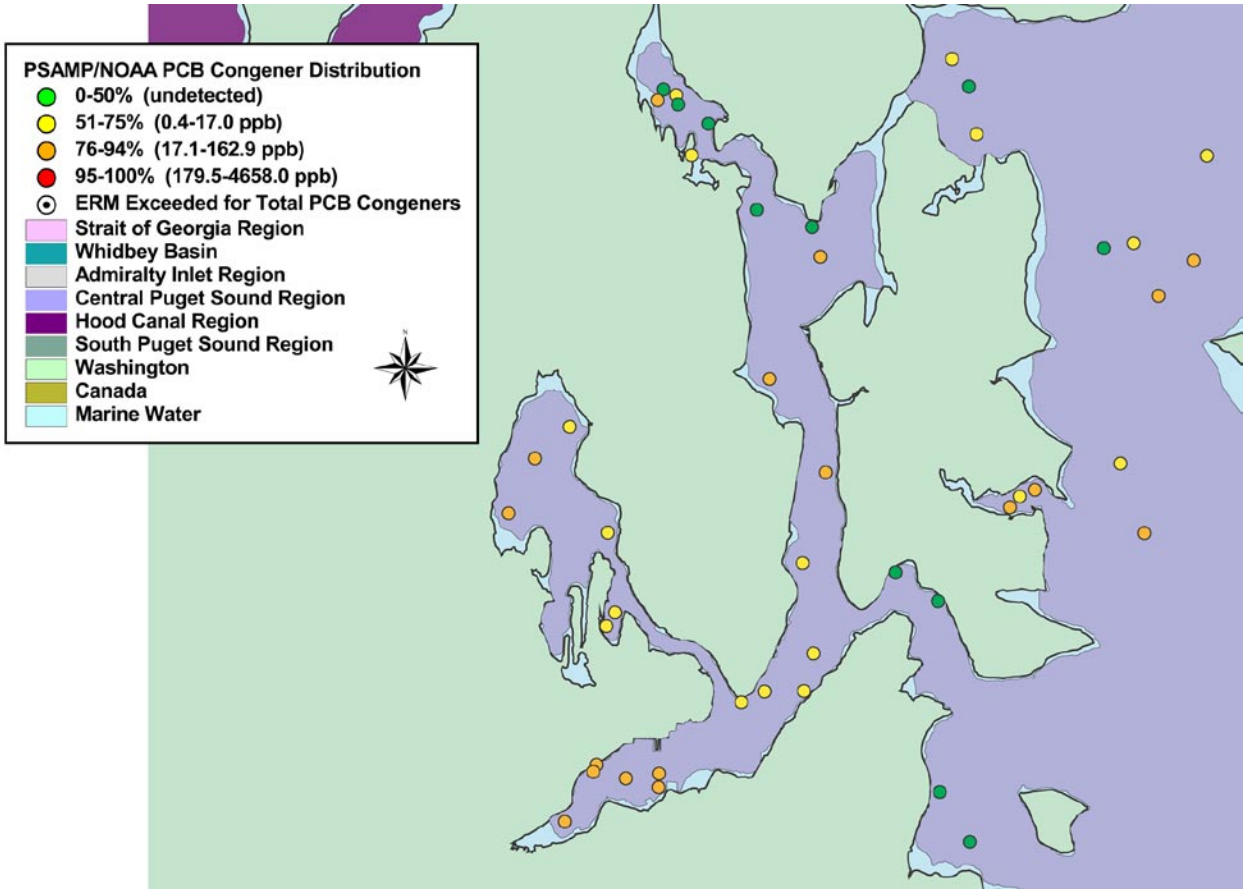

Figure 2. Distribution of total PCB congener concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Bainbridge Basin area, and comparison with nationally derived sediment quality guidelines (ERL and ERM, Long et al. 1995).

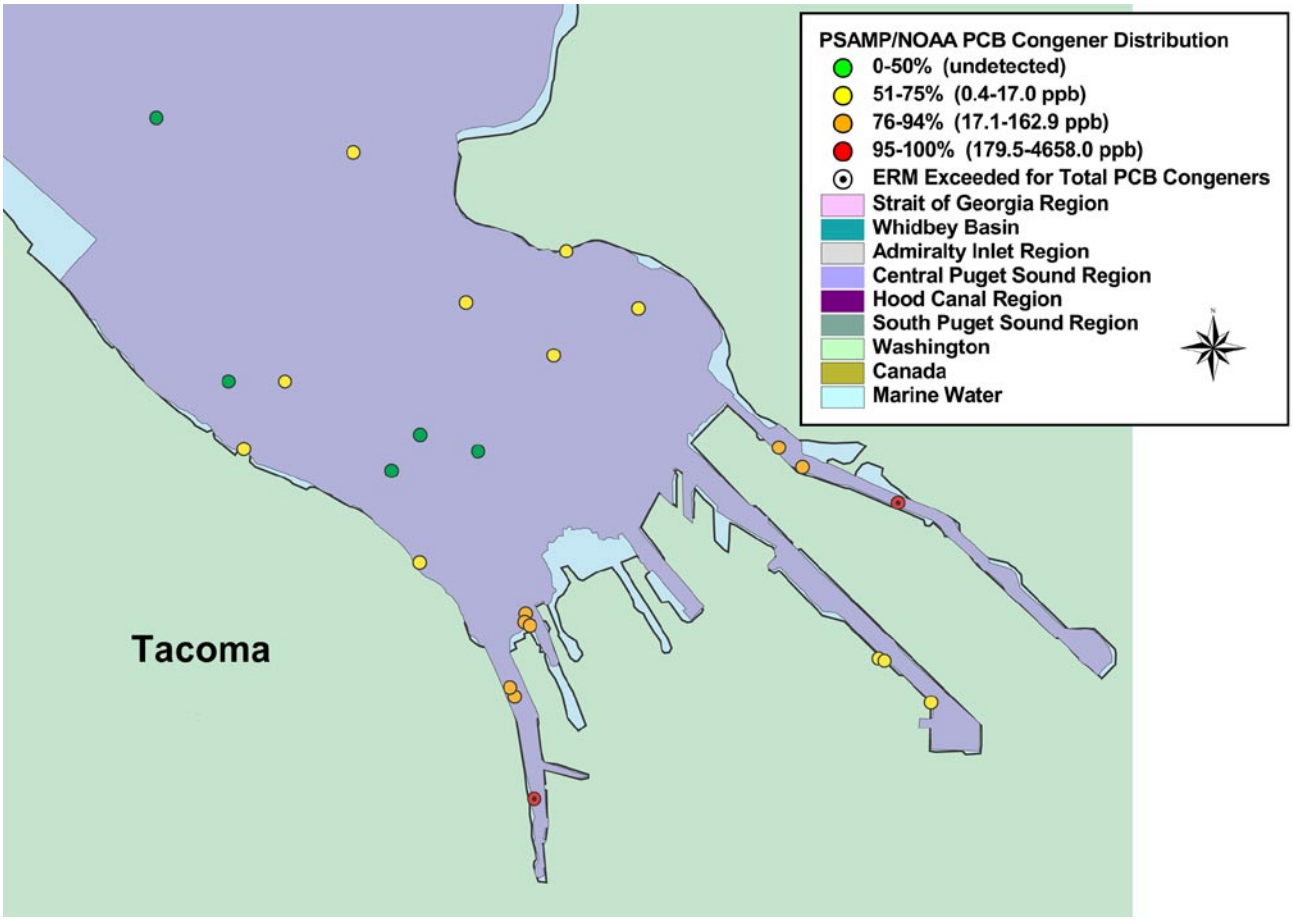

Figure 3. Distribution of total PCB congener concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Commencement Bay area, and comparison with nationally derived sediment quality guidelines (ERL and ERM, Long et al. 1995).

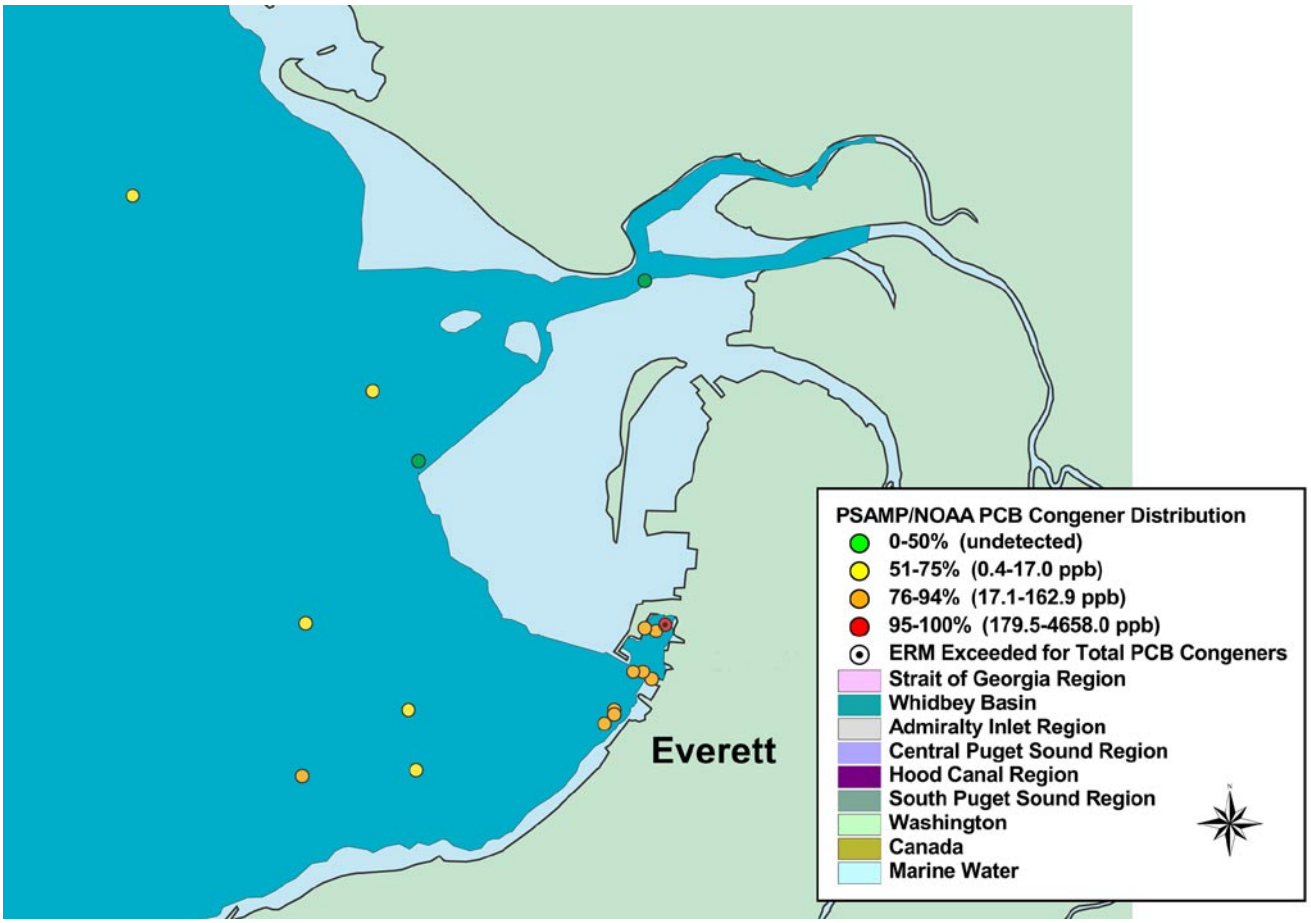

Figure 4. Distribution of total PCB congener concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Everett Harbor area, and comparison with nationally derived sediment quality guidelines (ERL and ERM, Long et al. 1995).

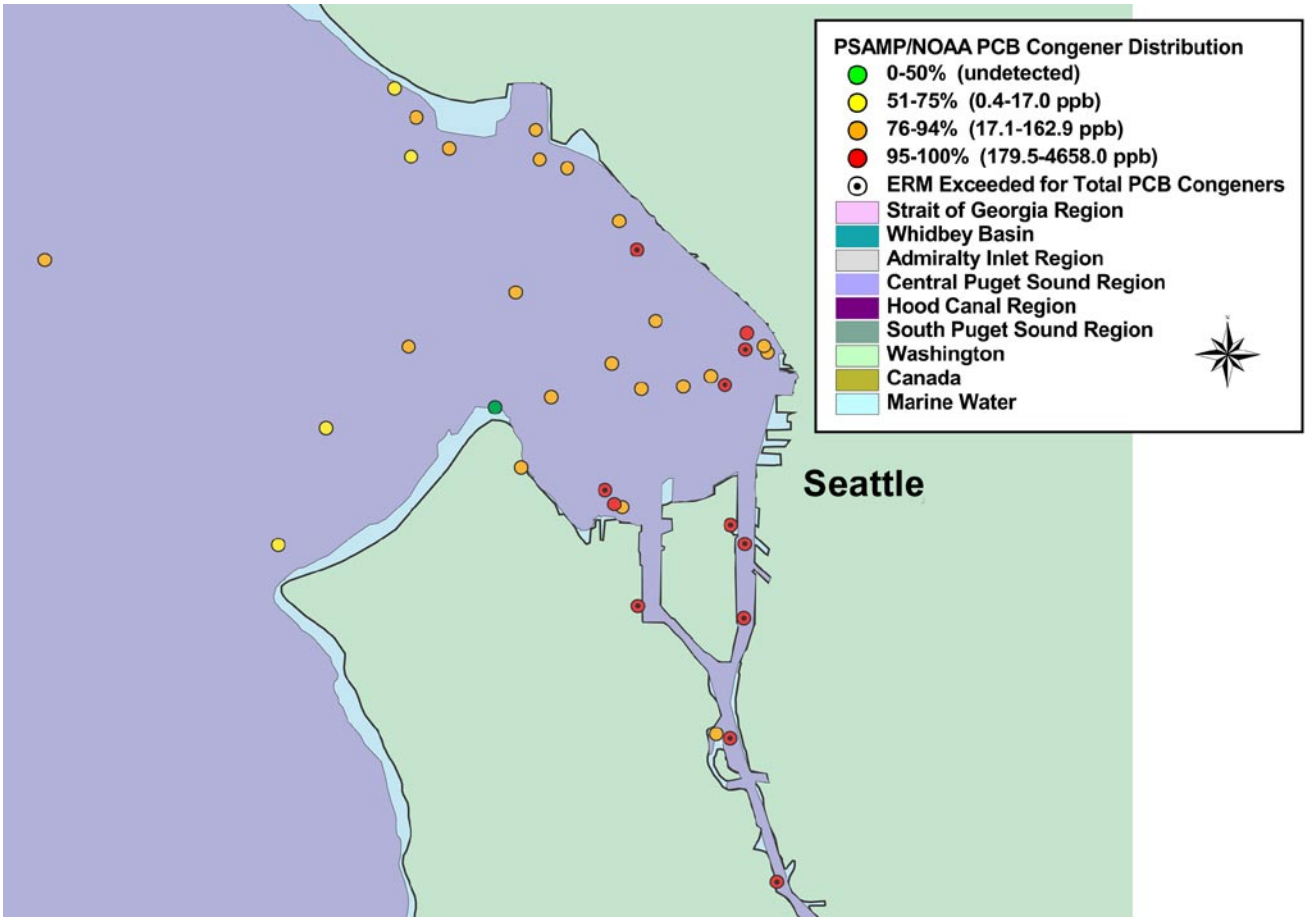

Figure 5. Distribution of total PCB congener concentrations (ppb, dry wt.) in sediments from the 1997-99 PSAMP/NOAA sediment survey—Elliott Bay area, and comparison with nationally derived sediment quality guidelines (ERL and ERM, Long et al. 1995).

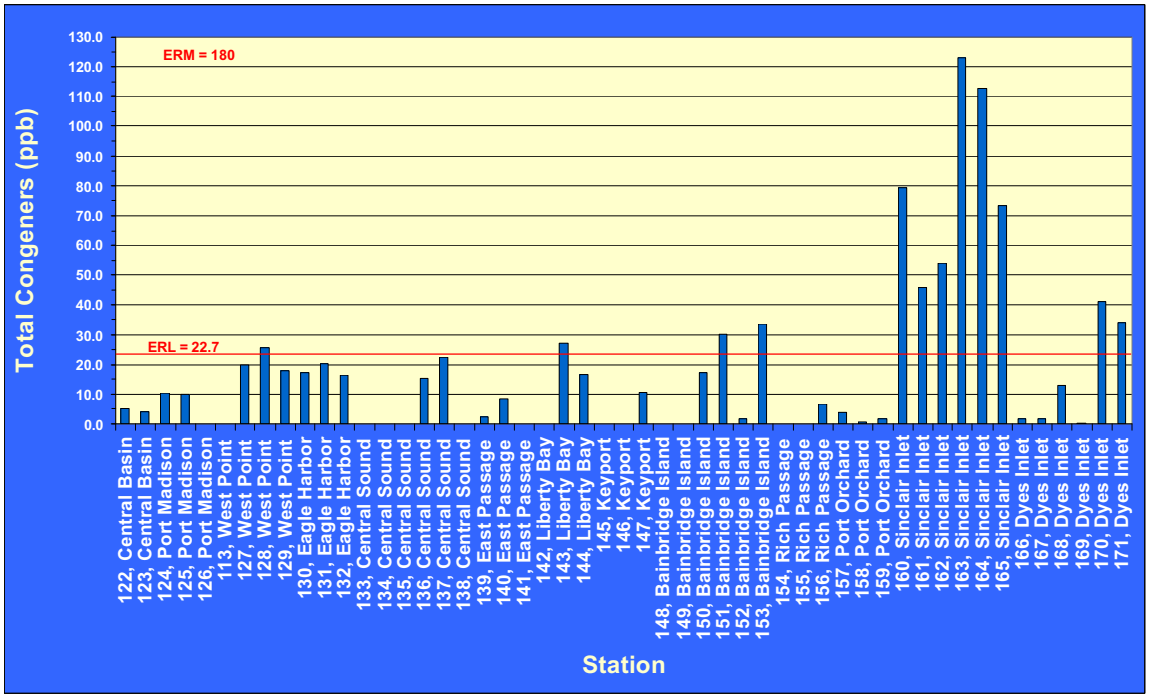

Figure 6. Total PCB congener concentrations (ppb) for the Bainbridge Basin sampled in the 1997-99 PSAMP/NOAA sediment quality survey.

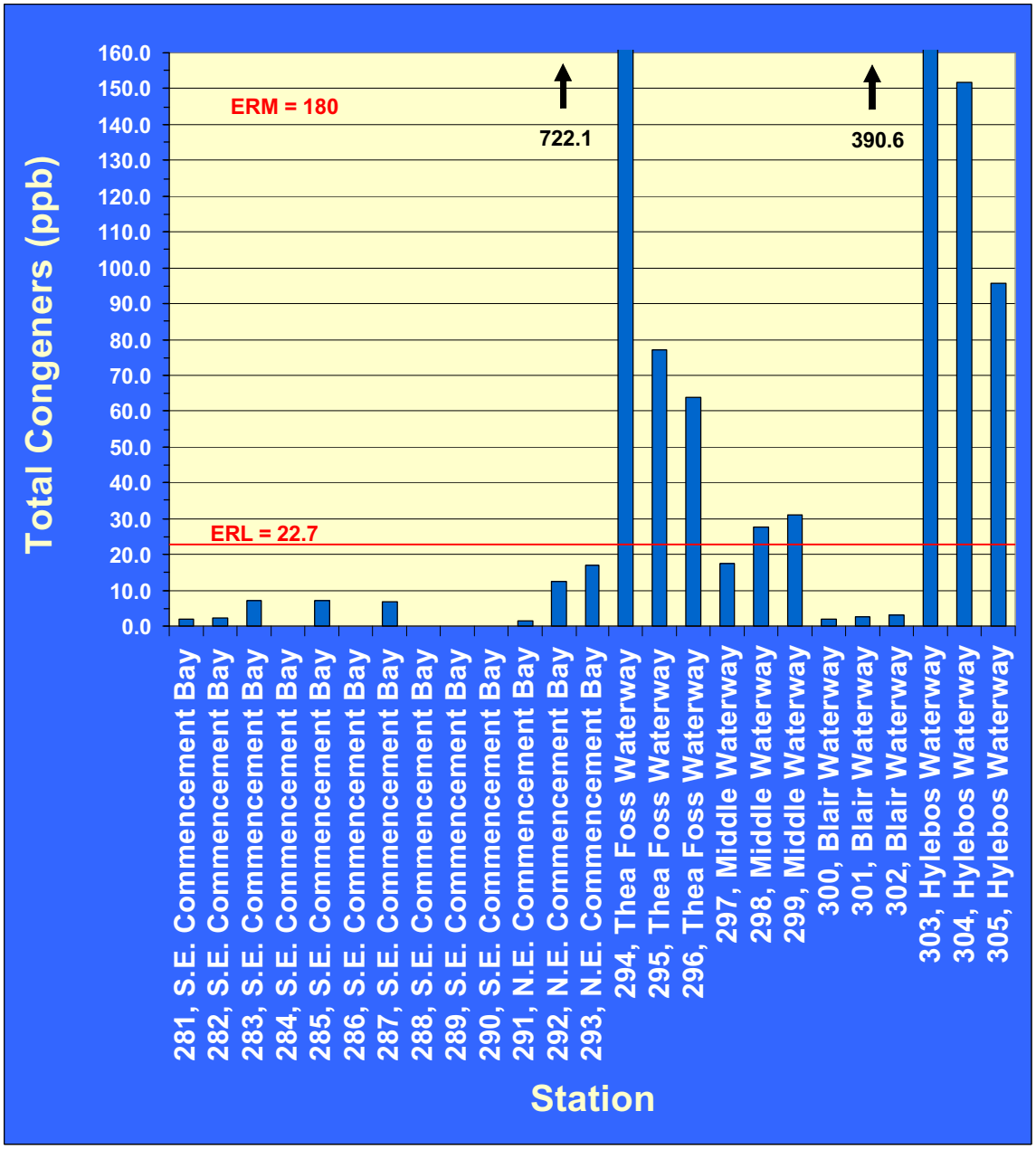

Figure 7. Total PCB congener concentrations (ppb) for Commencement Bay sampled in the 1997-99 PSAMP/NOAA sediment quality survey.

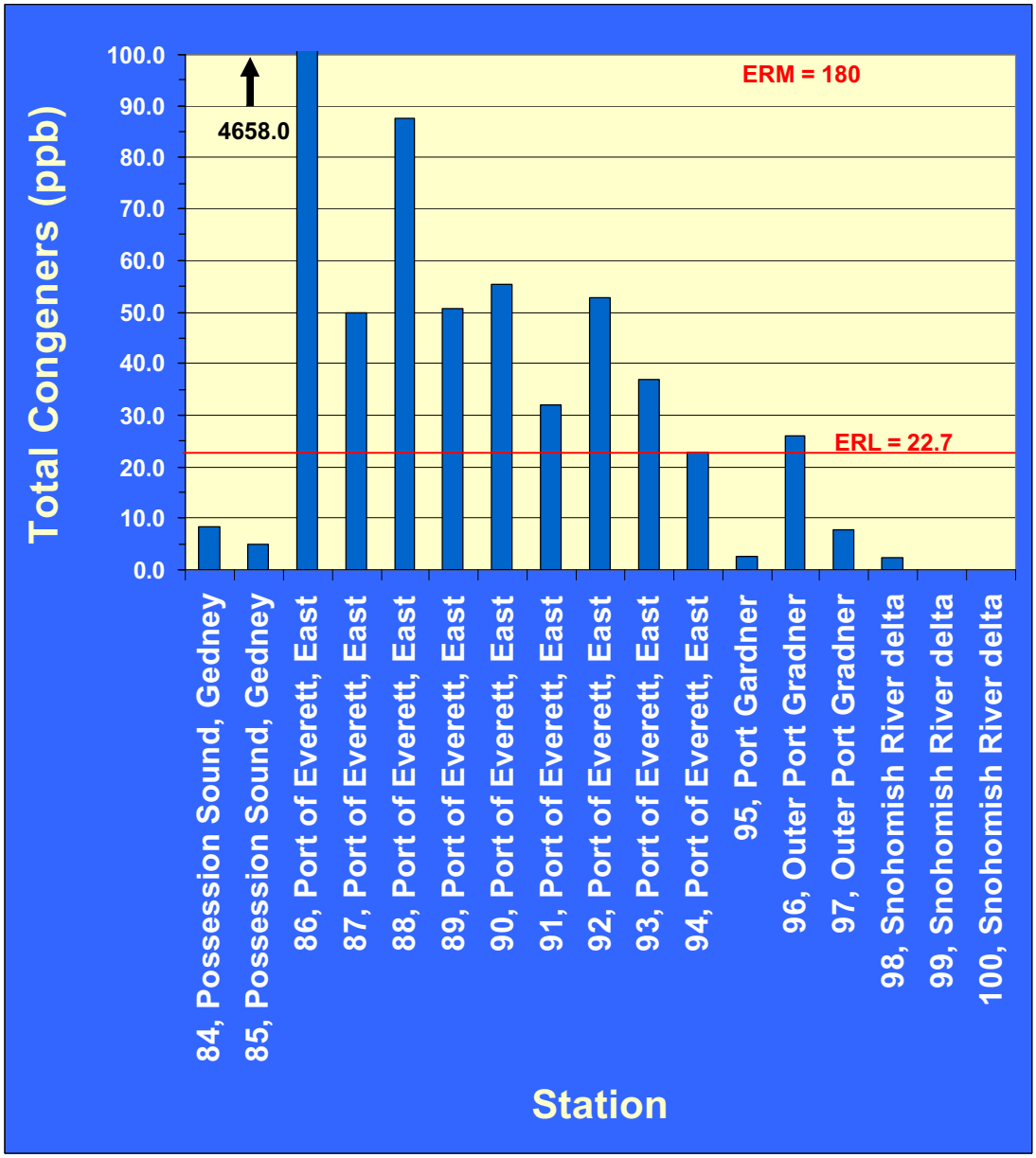

Figure 8. Total PCB congener concentrations (ppb) for Everett Harbor sampled in the 1997-99 PSAMP/NOAA sediment quality survey.

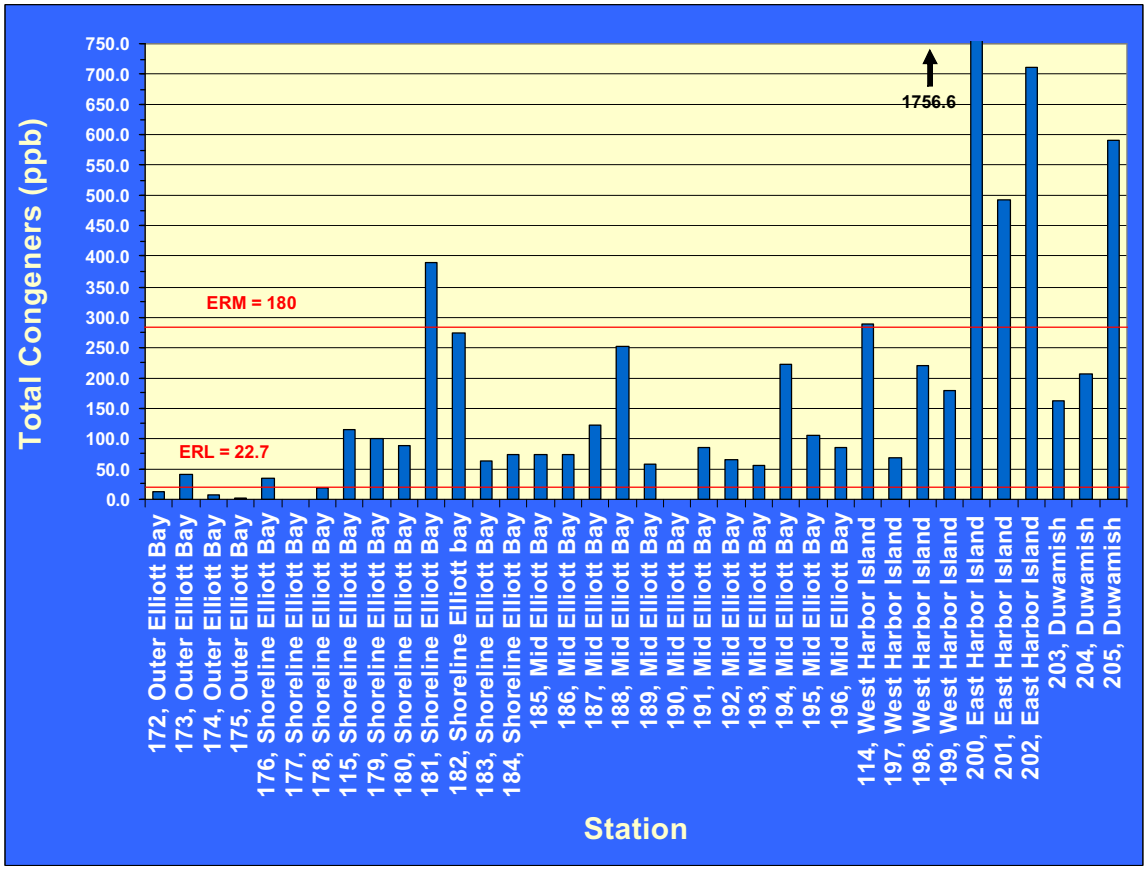

Figure 9. Total PCB congener concentrations (ppb) for Elliott Bay sampled in the 1997-99 PSAMP/NOAA sediment quality survey.